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THE EFFECT OF A CORNING DIESEL EXHAUST FILTER ON THE PNA CONCENTRATION AND MUTAGENICITY OF DIESEL EXHAUST

FINAL REPORT

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INTRODUCTION

The introduction of diesels into underground mines has increased the concentrations of several different pollutants in these mines (1). This arises because several gaseous pollutants such as CO_2, CO, NO, NO_2 and SO_2 are emitted by the diesels. In addition, respirable sized particulate (2), sulfuric acid (3,4) and unburned hydrocarbons and hydrocarbon derivatives (5-7) are also released from the diesel. The presence of these pollutants in the mine environment has been of concern in the industry for some time because miners working on or downstream from a diesel are exposed to higher concentrations of these pollutants. Although previous work has shown that most of these pollutants do not exceed the threshold limit concentrations for these substances in the mining environment (1,7), there is still concern about the amounts of sulfuric acid, diesel particulate and two types of hydrocarbons, the polynuclear aromatic hydrocarbons (PNAs or PAHs) and the nitrated polynuclear aromatic hydrocarbons or nitro PNAs. The presence of PNAs in the mine environment is of concern because several of these compounds are known carcinogens (8-10). The nitro PNAs cause concern because these compounds are highly mutagenic in the Ames Salmonella Bioassay (7,11-16).

The sulfuric acid levels are currently being investigated (3,4) and several different filters and/or catalytic converters that can be installed in the exhaust system of a diesel have

been devised in an attempt to reduce the amount of particulate, the PNAs and the nitro PNAs in the diesel exhaust.

None of the catalytic converters that are currently used in the mining industry reduce the PNAs or the nitro PNAs emitted by the diesel. In fact, the PNA levels and the mutagenicity (nitro PNAs) are higher in the air downstream from a diesel using a PTX or Dieseler III catalytic converter (7,11,17) and the mutagenicity of the Dieseler III exhaust is at least 10 times higher than the exhaust from a diesel with a PTX catalytic converter in the exhaust train (7). Obviously, these devices are not effective in reducing the PNA or the nitro PNA concentrations in the mine environment.[1]

A second approach has been to place a filtering device in the exhaust train of a diesel. This approach seemed attractive because it was believed that the filter would remove the particulate, the PNAs and the nitro PNAs from the exhaust. It was thought that the PNAs and nitro PNAs were strongly absorbed on the particulate. Thus, removing the particulate would also remove the PNAs and the nitro PNAs from the exhaust. One of the filters that has been tested extensively is the University of Waterloo—U.S.B.M. filter. Although this filter reduces the amount of particulate in the exhaust significantly, preliminary experiments(7) suggest that it does not reduce the PNA concentrations. Presumably, this filter does not remove

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[1]Preliminary tests on a new catalytic converter suggest that these devices might be able to reduce the amounts of PNAs and nitro PNAs in diesel exhaust (18).

the nitro PNAs either.

More recently, a new ceramic type of filter has been produced by the Corning Glass Company. Preliminary tests have shown (19) that 80 to 95% of the particulate is removed by this filter. Moreover, the soluble organic fraction (SOF) of the particulate is also reduced significantly by this filter. Similar results have been obtained in field trials in underground mines (20). It was important, therefore, to determine whether the PNAs and nitro PNAs were also reduced by the Corning filter. The work in this report addresses this question, i.e., the extracts from Hi Vol filters collected downstream from a diesel operating with and without the Corning filter in the exhaust train have been analyzed to determine whether the filter reduces the concentrations of the PNAs and the nitro PNAs (the mutagenicity) of the exhaust.

RESULTS AND DISCUSSION

The effect of adding a Corning Diesel Exhaust filter to the exhaust system of a diesel was determined by analyzing Hi Vol filters collected in the dilute exhaust, for PNAs and for nitro PNAs, i.e., the mutagenicity. The 912-W Deutz engine was mounted on a test stand in a 20' x 10' x 9' (high) bunker and controlled by a chassis dynamometer. Figures 1 and 2 show the side and top view of the bunker, the diesel and the sampling sites. The Hi Vol samples were collected approximately 9 feet downstream from the end of the exhaust system on 8" x 10" Pallflex T60A20 teflon coated glass fiber filters. The temperature of the exhaust gases was measured in the exhaust system and at the sampling site. The concentrations of carbon dioxide, carbon monoxide and the nitrogen oxides (NO_x) were also determined in the raw or undiluted exhaust and at the sampling site. The Hi Vol samples were collected at both High and Low ventilation rates. The ventilation rates were controlled by turning the ventilation fan in the roof of the bunker, Figure 1, from High to Low. The nominal ventilation was 7200 cfm when the fan was run on the High setting and 3600 cfm when it was on the Low setting. The sampling times were adjusted so that the flow rate through the Hi Vol filters did not decrease by more than 20 percent of the original flow rate during the sampling period. Samples which were collected when the diesel was operating on a cycle (see below), were always collected for a complete number of cycles.

Hi Vol samples were collected when the diesel was

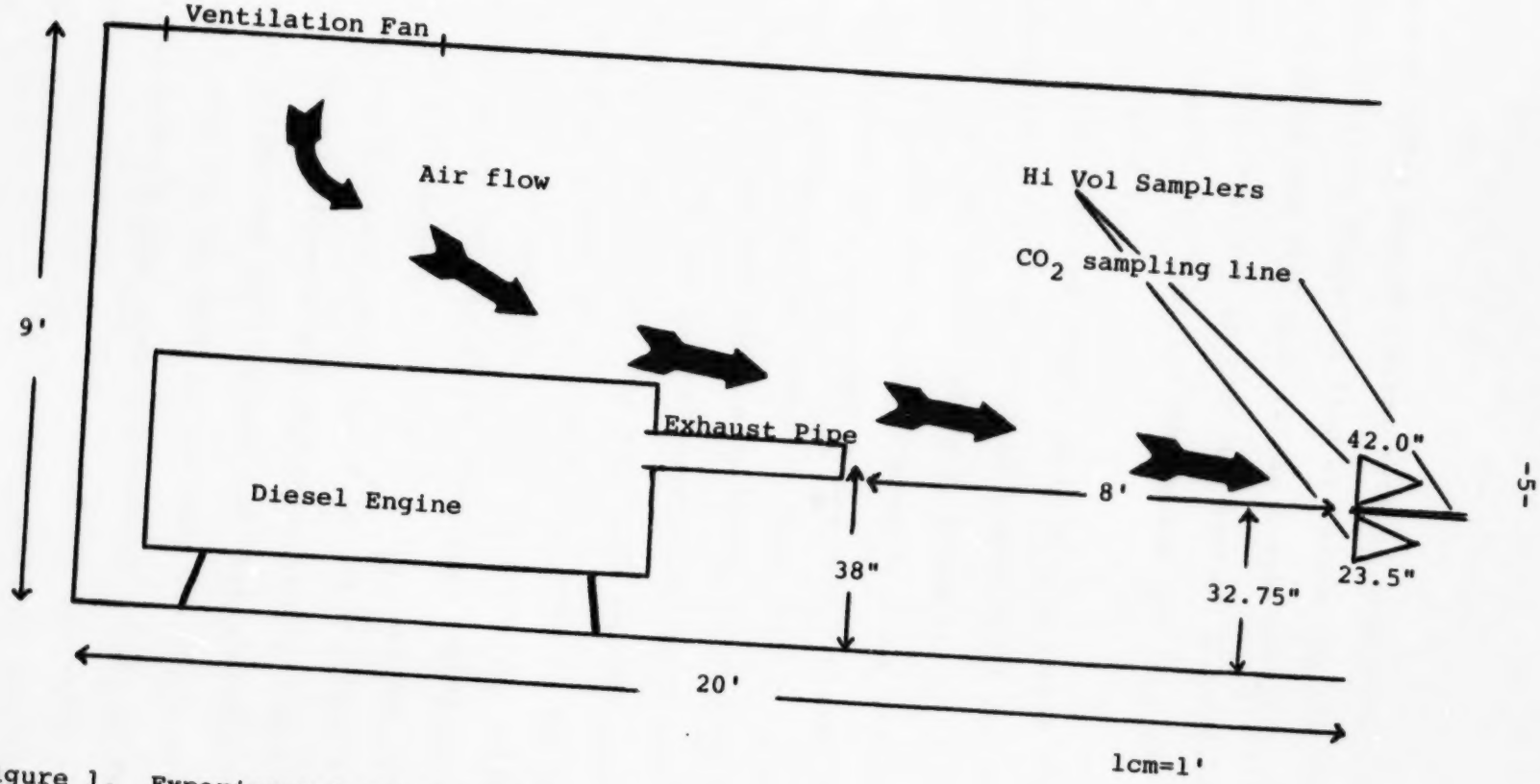

Figure 1. Experimental setup used in collecting the Hi Vol filters for PNA and Ames Analysis. (Side view).

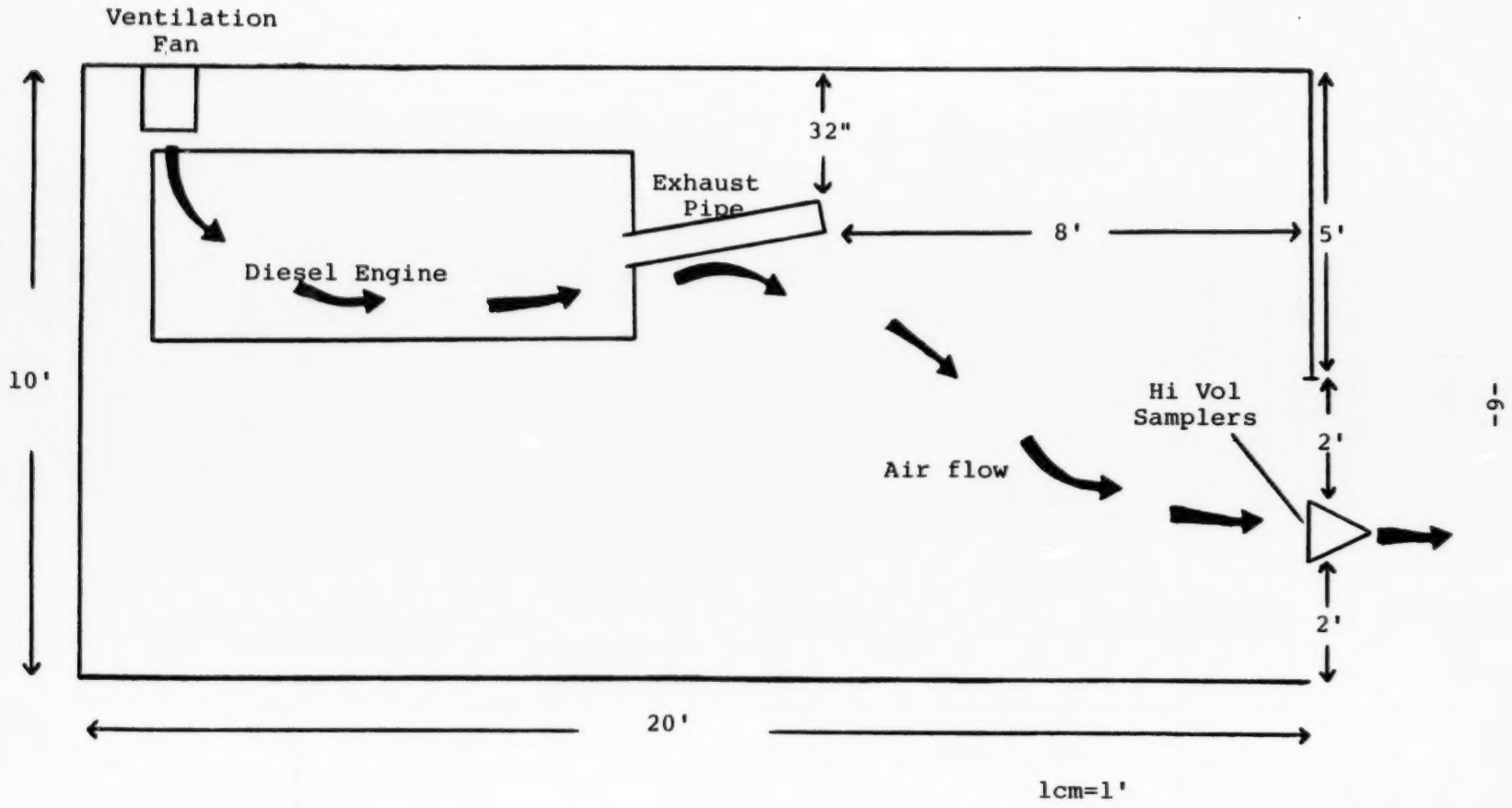

Figure 2. Experimental setup used in collecting the Hi Vol filters for PNA and Ames Analysis. (Top view).

operated under four different sets of conditions: i) a Steady-state condition where the load or torque was 156 ft-lbs and the engine speed was 2200 rpm; ii) an 8-Mode cycle; iii) a Modified 8-mode cycle and; iv) an Inco Hot cycle. A detailed description of the 8-Mode, the Modified 8-mode and the Inco Hot cycles is given in Table 1.

The Modified 8-mode cycle only differed from the 8-Mode cycle in that the Modified 8-mode cycle contained a 40 second lug-down period (phase 2, Table 1).

The Inco Hot cycle differed from the 8-Mode and Modified 8-mode cycles in that it had only 6 phases and a 45 second lug-down period (phase 2, Table 1). A comparison of the 8-Mode and the Modified 8-mode cycles enabled us to determine how a lug-down affected the PNA concentrations in the exhaust. The longer lug-down in the Inco Hot cycle was different from that in the Modified 8-mode cycle because the exhaust was hotter during the lug-down in the Inco Hot cycle. In fact, the temperature of the exhaust in the Corning filter went over 1000°F during the lug-down period (phase 2, Figure 3), in the Inco Hot cycle whereas the filter did not even reach 1000°F in the Modified 8-mode cycle, Figure 3. This difference was important in the experiments where the Corning filter was used because the back pressure of the filter decreased during the lug-down in the Inco Hot cycle (phase 2, Figure 4) indicating that some regeneration of the filter, i.e., that some of the particulate was burned off the ceramic inserts of the Corning filter during the lug-down phase of the Inco Hot cycle.

Table 1 - Types of simulated mining cycles used in testing the effect of a Corning Exhaust filter on a 912-W Deutz diesel engine.

Phase	Engine speed in rpm	Torque in ft-lbs	Elapsed Time in seconds
	8-Mode Cycle - No Lug-Down		
1	1840	195	0-40
2	1840	156	40-80
3	1610	59	80-90
4	1980	156	90-195
5	1840	78	195-250
6	1495	20	250-260
7	1980	68	260-270
8	650	0	270-300
	Modified 8-mode Cycle Including Lug-Down		
1	1840	156	0-40
2	1610*	222	40-80
3	1610	59	80-90
4	1980	156	90-195
5	1840	78	195-250
6	1495	20	250-260
7	1980	68	260-270
8	650	0	270-300
	Inco Hot Cycle Including Lug-Down		
1	2000	196	0-15
2	1625*	222	15-60
3	2300	146	60-170
4	2200	195	170-180
5	1500	98	180-190
6	2300	171	190-300

* Lug-down period

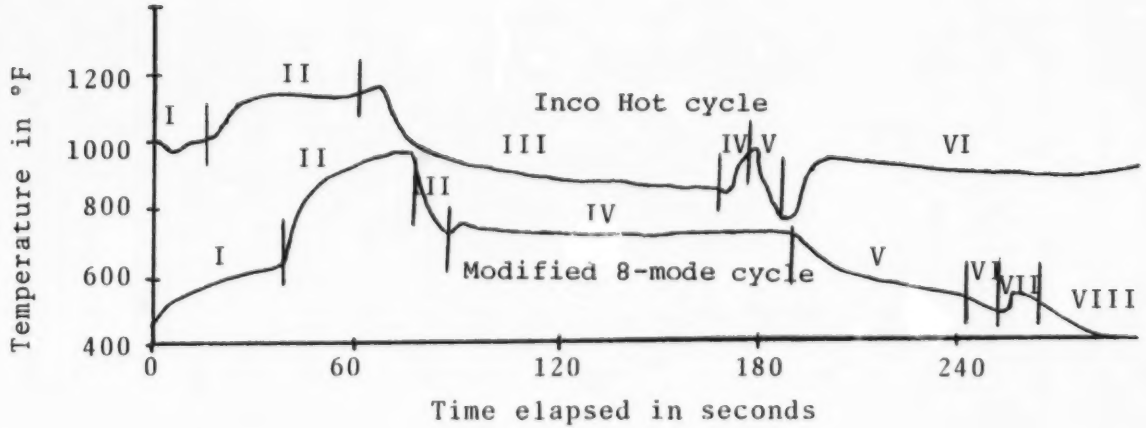

Figure 3. Temperature of the Corning Filter during the Inco Hot cycle and the Modified 8-mode cycle. The phases are marked in roman numerals.

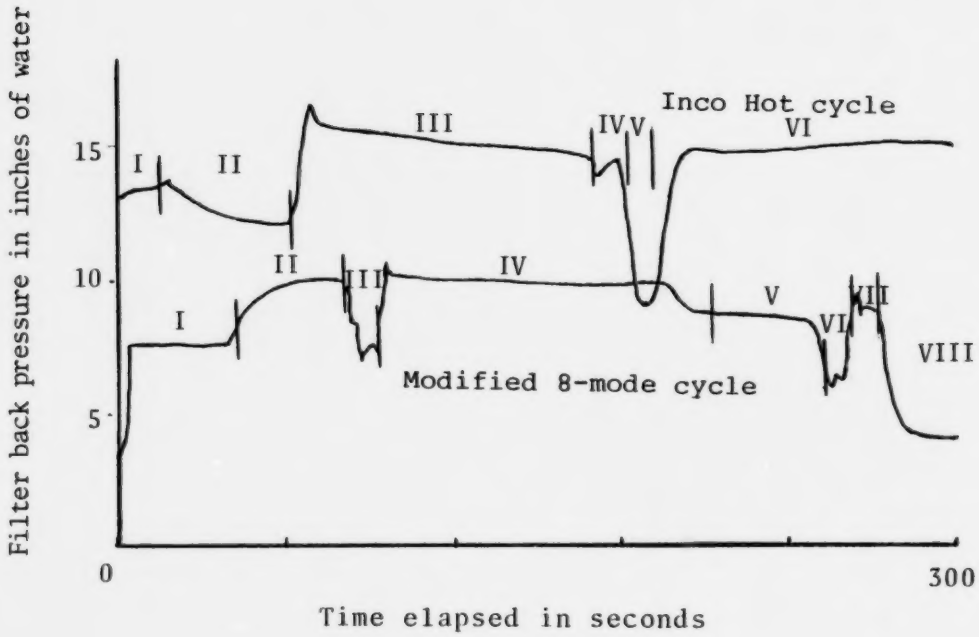

Figure 4. Corning filter back pressure in inches of water found for the Inco Hot cycle and the Modified 8-mode cycle. The phases are marked on each curve in roman numerals.

No regeneration was apparent during the lug-down in the Modified 8-mode cycle, Figure 4, and thus the Modified 8-mode and Inco Hot cycles are significantly different. Samples from the Modified 8-mode and Inco Hot cycles collected when the Corning filter was present and absent from the exhaust systems were analyzed for PNAs and for mutagenicity in order to determine how i) the type of cycle and ii) the regeneration of the filter during the Inco Hot cycle affected the PNA levels and the mutagenicity of the exhaust.

Sampling Efficiency:-

Before the effect of the different cycles could be examined, it was necessary to determine how the experimental design affected the results. This was important because samples could be collected when the ventilation fan in the bunker, Figures 1 and 2, was run on a High setting or on a Low setting. It was important to ascertain how the ventilation rate affected the PNA concentrations because the temperature at the sampling sites was approximately 20°F (10°C) lower when the ventilation rate was 7200 cfm than when it was 3600 cfm. This was of concern because previous work in our laboratory had suggested that the sampling efficiency was temperature dependent (7). The lower sampling or collection efficiencies found for the PNAs at higher temperatures could have arisen because i) more of the PNAs passed through the filter as a vapour and/or ii) because the PNAs were desorbed (lost) from the particulate on the Hi Vol filter as more hot air was drawn through the filter, i.e., as the sampling time increased.

Hi Vol samples collected at High and Low ventilation rates when the 912-W Deutz diesel was run under Steady-state conditions and in the 8-Mode cycle, were analyzed to determine the influence of temperature on the sampling efficiency. This experiment was posssible because increasing (doubling) the ventilation rate should increase (double) the dilution ratio at the sampling site. Thus, the PNA concentrations at the sampling site at High ventilation would be one-half of those at the sampling site at Low ventilation. If the sampling efficiency were the same at the two temperatures, the PNA concentrations in the samples collected at High ventilation (7200 cfm) would be fifty percent of those found at Low ventilation, i.e., when the ventilation was 3600 cfm. If on the other hand, the collection efficiency is greater at lower temperatures as previous work has suggested, the PNA concentrations found when the samples were collected at 7200 cfm would be higher than the PNA concentrations expected at High ventilation, i.e., the PNA concentrations would be more than one-half the PNA concentrations found when the Hi Vol filters were collected at the Low ventilation rate.

The PNA concentrations found at the Low ventilation rate of 3600 cfm for two different operating conditions, the Steady-state condition and the 8-Mode cycle, are shown in Table 2. A comparison of the PNA concentrations in the air at High ventilation with the expected PNA concentrations at High ventilation (half of the Low ventilation PNA concentrations) are given in Table 3. An examination of the results in Table 3 shows that the

Table 2 - PNA concentrations found when a 912-W Deutz diesel was operated in the bunker under Steady-state and in the 8-Mode cycle with the Low ventilation rate of 3600 cfm.

	Concentration in ng/m^3				
	Steady-state Operation				8-Mode Cycle
	Filter#10	Filter#5	Filter#6	Average Steady-state	Filter#14
Pyrene	349	255	350	318	185
Fluoranthene	61.2	38.7	31.0	43.6	88.7
Benzo(a)anthracene*	46.7	101	110	85.9	30.9
Benzo(e)pyrene	178	137	51.3	122	176
Perylene	1.19	0.89	7.54	3.21	3.08
Benzo(k)fluoranthene	70.2	39.4	45.2	51.6	41.4
Benzo(a)pyrene*	0.82	1.91	6.19	2.97	17.2
Benzo(ghi)perylene*	31.3	43.5	54.1	43.0	42.9
Dibenzo(a,h)anthracene*	21.0	11.3	0	10.8	15.6
Dibenzo(def,mno)chrysene	1.70	1.08	0	0.93	1.27
Naptho(1234,def)chrysene*	43.9	20.0	43.6	35.8	5.70
Benzo(rst)pentaphene*	5.27	3.14	16.2	8.20	3.86
Total PNAs	810	613	715	713	612
Total-pyrene	461	359	365	395	427
Total Carcinogens	149	181	230	187	116
Average Temperature at sampling site (°F)	115	115	115	115	100
Average Dilution Ratio (CO_2)	32/1	32/1	32/1	32/1	32/1
Average Dilution Ratio (NO_x)	36/1	36/1	36/1	36/1	36/1

* Carcinogenic PNA

Table 3 - The PNA concentrations, the expected PNA concentrations and the collected/expected ratios found when a 912-W Deutz diesel was operated in the bunker under Steady-state and in the 8-Mode cycle with the High ventilation rate of 7200 cfm

	Concentrations in ng/m^3								
	Steady-state Conditions								
	Observed High ventilation Sample#2	PNA concentrations expected from Low ventilation Sample #10	Sample #5	Sample #6	Average 10,5,6	% Expected High ventilation Sample #10	Sample #5	Sample #6	Average 10,5,6
Pyrene	285	174	128	175	159	164	223	163	179
Fluoranthene	28.1	30.6	19.4	15.5	21.8	92	145	181	129
Benzo(a)anthracene*	137	23.3	50.5	55	43.0	588	271	249	319
Benzo(e)pyrene	92.1	89	68.5	25.6	61.0	103	134	360	151
Perylene	2.09	0.59	0.44	3.77	1.60	354	475	55	131
Benzo(k)fluoranthene	28.9	35.1	19.7	22.6	25.8	82	147	128	112
Benzo(a)pyrene*	10.0	0.41	0.96	3.10	1.48	2439	1042	322	676
Benzo(ghi)perylene*	32.6	15.6	21.8	27.0	21.5	209	150	121	152
Dibenzo(a,h)anthracene*	0	10.5	5.65	0	5.40	0	0	0	0
Dibenzo(def,mno)chrysene	1.25	0.85	0.54	0	0.47	147	231	0	266
Naptho(1234,def)chrysene*	20.3	21.9	10.0	21.8	17.9	93	203	93	113
Benzo(rst)pentaphene*	5.05	2.63	1.57	8.10	4.10	192	322	62	123
Total PNAs	642	405	307	358	356	158	210	180	180
Total-pyrene	357	231	180	183	198	155	199	196	180
Total Carcinogens	205	74.5	90.5	115	93.5	275	227	178	219
Average Temperature at the sampling site (°F)	94	115	115	115	115				
Dilution Ratio CO_2	71/1±11								
Dilution Ratio NO_x	114/1±38								

* Carcinogenic PNAs

Table 3 continued - The PNA concentrations, the expected PNA concentrations and the collected/expected ratios found when a 912-W Deutz diesel was operated in the bunker under Steady-state and in the 8-Mode cycle with the High ventilation rate of 7200 cfm

	Concentrations in ng/m^3		
	8-Mode Cycle		
	Observed High ventilation Sample#6	Expected PNA Concentrations from the Low ventilation Sample#14	% High ventilation / Expected High ventilation
Pyrene	149	92.5	161
Fluoranthene	40.9	44.3	92
Benzo(a)anthracene*	29.7	15.4	192
Benzo(e)pyrene	145	88.0	165
Perylene	2.30	1.54	149
Benzo(k)fluoranthene	15.8	20.7	76
Benzo(a)pyrene*	13.0	8.60	151
Benzo(ghi)perylene*	27.6	21.5	129
Dibenzo(a,h)anthracene*	33.7	7.80	432
Dibenzo(def,mno)chrysene	0.64	0.64	100
Naptho(1234,def)chrysene*	12.7	2.85	446
Benzo(rst)pentaphene*	2.30	1.93	119
Total PNAs	434	306	142
Total-pyrene	285	213	133
Total Carcinogens	85.3	58.0	147
Average Temperature at the sampling site (°F)	not measured	100	
Dilution Ratio CO_2	71/1±11		
Dilution Ratio NO_x	114/1±38		

* Carcinogenic PNAs

temperature at the sampling site plays an important role in determining the amount of PNAs that are collected on a Hi Vol filter. For example, with one or two exceptions, the PNA concentrations in the samples collected at High ventilation when the diesel was operating in the Steady-state mode (column 1, Table 3) are considerably higher than those expected at the High ventilation rate (columns 2-4) and all of the PNAs in the High ventilation sample are more concentrated than the average expected High ventilation PNA concentrations (column 5, Table 3). The magnitude of the temperature effects is best seen by examining the ratios of (the PNA concentrations found at High ventilation / the PNA concentrations expected at High ventilation) x 100%, (columns 6-9, Table 3). Almost all of these ratios are greater than 100% and moreover, the Total PNAs, Total-pyrene and the Total Carcinogenic PNAs range from 158% to 210% (an average of 180%), 155% to 199% (an average of 180%) and from 178% to 275% (an average of 219%) respectively, higher than those expected. Thus, a decrease of 21°F (12°C) increases the sampling efficiency by close to 100%, i.e., almost twice as much PNAs are collected at the lower temperature.

The same trend is observed for the samples collected during an 8-Mode cycle, Table 3, continued. In this case, however, the results are less spectacular, i.e., two of the PNA concentrations at High ventilation are lower than the PNA concentrations expected at High ventilation and the Total PNAs, Total-pyrene and Total Carcinogenic PNAs are only 142%, 133% and

147% respectively, of those expected at High ventilation. Unfortunately, these results were obtained from only one sample and the analyses were done by an inexperienced analyst. Another problem was that the temperature was not recorded for the 8-Mode cycle at High ventilation and thus we do not know how much the temperature decreased when the ventilation was increased. In spite of the difficulty in making quantitative comparisons from these results, it is clear that the collection efficiency increases significantly when the temperature at the sampling site decreases. This is obviously a factor that will have to be considered in collecting Hi Vol samples for PNA and probably for Ames testing.

It is worth noting that the sampling site dilution ratios that were used in the above calculations were determined from the nominal speed of the ventilation fan. In fact, the dilution ratio at the sampling site can also be determined by measuring the percent CO_2 and/or the NO_x concentrations in the air at the sampling site at High and Low ventilation. When this was done, the dilution ratios calculated from the percent CO_2 were 32/1 at Low ventilation (Table 2) and 71/1 at High ventilation (Table 3). The corresponding dilution ratios based on the NO_x concentration at the sampling site were 36/1 at Low ventilation and 114/1 at High ventilation. Thus, changing the ventilation diluted the exhaust (PNAs) at the sampling site by 2.0 when the nominal fan speed was used, 71/32=2.21 when the percent CO_2 at the sampling site was used, and by 114/36=3.17 when the NO_x concentrations at the sampling site were used. If the change in

the dilution ratio at the sampling site were based on the percent CO_2 and the NO_x concentrations, the sampling efficiency increases even more than the data in Table 3 suggests when the temperature of the sampling site decreases by 21°F. Table 4 gives the (PNA concentrations at High ventilation / PNA concentrations expected at High ventilation) x 100% using i) the nominal fan speed, ii) the percent CO_2 at the sampling site and iii) the NO_x concentrations at the sampling site to estimate the change in the dilution ratio when the ventilation was increased. These results indicate that the collection efficiency is between 200 to 300% higher when the temperature is decreased by 21°F at the sampling site, i.e., less than 50% and possibly less than 33% of the PNAs collected at 94°F will be collected when the temperature is 115°F at the sampling site. These results clearly indicate that the Hi Vol sampling method is far from quantitative when the sampling temperature is greater than 100°F and suggest that the Hi Vol method is not trapping the PNAs quantitatively under any conditions (7).

The Effect of Different Cycles;-

The PNA and Ames analyses of the Hi Vol filters collected when the 912-W Deutz diesel was operating on the 8-Mode cycle, the Modified 8-mode cycle, the Inco Hot cycle and under Steady-state conditions enabled the authors to determine how the different modes of operation affected the PNA concentrations and the mutagenicity of the exhaust at the sampling site. All of the available PNA

Table 4 - The $\left(\frac{\text{PNA concentrations at High ventilation}}{\text{PNA concentrations expected at High ventilation}}\right)$ X 100% found when the dilution ratios at the sampling site were calculated using the nominal fan speed, the percent CO_2 and the NO_x concentrations at the sampling site

Type of Cycle		$\left(\frac{\text{PNA concentrations at High ventilation}}{\text{PNA concentrations expected at High ventilation}}\right)$ x 100% for Nominal fan speed	Percent CO_2	NO_x concentration
Steady-state[a]	Total PNAs	183	202	262
	Total-pyrene	183	202	262
	Total Carcinogens	227	251	324
	Average	198	218	283
8-Mode[b]	Total PNAs	142	157	225
	Total-pyrene	133	147	190
	Total Carcinogens	147	162	210
	Average for all 4 samples	170	187	246

[a] These values are the average of three different samples.

[b] This result was obtained from one sample analyzed by a less experienced analyst.

concentrations and mutagenicities for the dilute exhaust from the four different operating modes are given in Table 5.

The first comparison is between the Modified 8-mode (with lug-down) cycle and the Inco Hot cycle. The results show that the PNA levels in the exhaust are virtually identical whether the diesel is operating on the Modified 8-mode cycle or on the Inco Hot cycle. However, the temperature was approximately 20°F higher at the sampling site during the Inco Hot cycle than during the Modified 8-mode cycle. Since increasing the temperature at the sampling site by 20°F reduces the amount of PNAs collected (the collection efficiency) by between 200 and 300%, one is forced to conclude that the PNAs are 2 to 3 times more concentrated in the exhaust from the Inco Hot cycle. Obviously then, the PNA levels are altered significantly by the type of cycle.

Although the observed specific mutagenicities[1] of the extract from the Hi Vol filters collected when the diesel was working on the Modified 8-mode and Inco Hot cycles are the same (the averages of the specific mutagenicities for the two different cycles are 0.61) it is highly probable that the correct specific mutagenicity of the extract from the Inco Hot cycle is 2 to 3 times higher than that from the Modified 8-mode cycle. If the trapping efficiency of the nitro PNAs which account for 36±10% of the observed mutagenicity, is related to temperature in the same way as the trapping efficiencies of the PNAs, a smaller percentage of the mutagenic material in the exhaust will be trapped on the filter

1. The Ames analyses were done by Mr. A.J. Horton, Ontario Research Foundation, Mississauga, Ontario.

Table 5 - The PNA concentrations and mutagenicity found at high ventilation when a 912-W Deutz diesel was operating on the Modified 8-mode cycle, the Inco Hot cycle and under Steady-state conditions.

PNA	Concentration in ng/m^3			
	Modified 8-mode	Inco Hot cycle	Steady-state	8-Mode
Pyrene	462	529	285	149
Fluoranthene	115	126	28.1	40.9
Benzo(a)anthracene*	56.4	42.3	137	29.7
Benzo(e)pyrene	179	177	92.1	145
Perylene	4.69	2.78	2.09	2.30
Benzo(k)fluoranthene	30.4	24.1	28.9	15.8
Benzo(a)pyrene*	11.7	11.6	10.0	13.0
Benzo(ghi)perylene*	43.0	28.4	32.6	27.6
Dibenzo(a,h)anthracene*	0	0	0	33.7
Dibenzo(def,mno)chrysene	2.65	3.03	1.25	0.64
Naptho(1234,def)chrysene*	28.8	28.6	20.3	12.7
Benzo(rst)pentaphene*	6.07	4.73	5.05	2.30
Total PNAs	940	977	642	434
Total-pyrene	478	448	357	285
Total Carcinogens	146	116	205	85.3
Average Temperature at the Sampling Site	74±7 °F	93±4 °F	99 °F	not measured
Specific Mutagenicity[a] TA98-S9	0.49,0.72	0.34,0.88		
Average Revertants/m^3[a] TA98-S9	648,1165	274,413		
Average Revertants/m^3[a] TA98+S9	1150	408		
Average Revertants/m^3[a] TA98-NR	304, 680	314, 197		

* Carcinogenic PNA

[a] These analyses were done by A.J. Horton, Ontario Research Foundation, Mississauga, Ont. The original data is given in the Appendix.

at the higher sampling temperature used in the Inco Hot cycle. Since the observed specific mutagenicities for the two cycles are equal, the actual specific mutagenicity of the exhaust from the Inco Hot cycle must be higher than that from the Modified 8-mode cycle. The average revertants/m^3 of the exhaust at the sampling site are higher for the Modified 8-mode cycle than for the Inco Hot cycle, regardless of the Salmonella strain (TA98 with S9, TA98 without S9 and TA98-NR) used in the Ames bioassay. In fact, the exhaust from the Inco Hot cycle is between 40 and 50% as mutagenic as the exhaust from the Modified 8-mode cycle. Again, however, these conclusions are probably misleading. When one considers that the temperature at the sampling site in the Inco Hot cycle is 20°F above the temperature at the sampling site in the Modified 8-mode cycle, one is forced to conclude that the average revertants/m^3 are equal to or higher for the Inco Hot cycle. Thus, the most probable result is that the specific mutagenicity and the average revertants/m^3 of the exhaust with TA98+ and -S9 and with TA98-NR are higher for the Inco Hot cycle than for the Modified 8-mode cycle. Again, one is forced to conclude that the type of cycle influences the PNA concentrations and the mutagenicity of the exhaust.

It is worth noting that these results are unusual in two ways. First, the PNA concentrations in the exhaust from the 912-W Deutz diesel used in this test are significantly higher than the PNA levels found downstream from any other diesel we have tested. In fact, the PNA concentrations in these samples are

approximately twice the highest concentrations we have found in an underground mine. This is particularly true when one considers i)that the dilution ratio was lower (the PNA concentrations should have been higher) at the sampling site in this test than those in most of our mine samples and ii) that the mine samples were collected at lower temperatures where the collection efficiencies should be higher than those at the sampling site in this study.

The specific mutagenicities and the average revertants/m^3 with TA98-S9 and with TA98+S9 are equal to or slightly lower than those found underground when the L714 series Deutz diesels were tested (7). Although the low values may be a result of the higher sampling temperatures used in this study, the results are not out of line with those obtained in our previous studies (7). What is unusual however, is that the samples still give a significant mutagenic response when the TA98-NR Salmonella strain of bacteria is used in the Ames analysis. In fact, the revertants/m^3 found when the TA98-NR is used are equal to 54% (Modified 8-mode), and 74% (Inco Hot cycle) of the corresponding values found when TA98-S9 is used in the Ames analysis. This means that 64±10% of the mutagenicity cannot be attributed to mononitro PNAs. This result was unexpected because almost all (approximately 85 percent) of the mutagenicity of the exhaust from the L714 series of Deutz diesels could be attributed to mononitro PNAs (7,17). Thus, the exhaust from the 912-W engine is peculiar for two reasons;it is very rich in i) PNAs and ii) in mutagens that respond to the TA98-NR strain of Salmonella bacteria, i.e., polynitro PNAs or non-nitrated PNAs. Unfortunately, we do not know whether these high PNA concentrations and low concentrations of mononitro PNAs are a

result of the type of fuel that was used in this experiment or whether they are characteristic of the 912-W Deutz diesel.

The next comparisons are between the Steady-state operation and the Modified 8-mode and Inco Hot cycles. A direct comparison can be made between the Inco Hot cycle and the Steady-state condition because the temperature at the sampling sites was identical for these two modes of operation. Generally, the PNA concentrations are lower in the Steady-state exhaust than they are in the exhaust from the Inco Hot cycle. In fact, the Total PNAs and the Total-pyrene for the Steady-state exhaust are only 66% and 80% respectively, of those found in the exhaust from the Inco Hot cycle. An important difference exists between the Steady-state condition and the Inco Hot cycle however. Three of five of the carcinogenic PNAs are more concentrated in the Steady-state exhaust, one other carcinogenic PNA is the same in the two exhausts and the final carcinogenic PNA is only 30% lower in the Steady-state exhaust. Moreover, the Total Carcinogenic PNAs are 177% more concentrated in the Steady-state exhaust than they are in the Inco Hot cycle exhaust. Again, it appears that the PNA concentrations in the dilute exhaust are different when the diesel is operated in a different manner. Unfortunately, no Ames testing was carried out on a Hi Vol filter collected under Steady-state conditions so we do not know how the mutagenicities of the exhaust from the two modes of operation are related.

When the PNA concentrations in the exhaust from the Steady-state and Modified 8-mode cycles are compared, the

relationships between the two modes of operation appear identical to those found with the Inco Hot cycle and the Steady-state mode.

However, when one realizes that the sampling temperature for the Modified 8-mode cycle was only 74±7°F, or 20°F below the temperature at the sampling site for the Steady-state mode, one is forced to conclude that the PNA exhaust levels are probably higher for the Steady-state condition than for the Modified 8-mode cycle. For example, if the collection efficiency is 250% higher at 74°F than it is at 94°F (see Table 4), the Total PNAs, the Total-pyrene and the Total Carcinogenic PNAs in the Steady-state exhaust are 171%, 187% and 351% respectively, of those found in the exhaust from a Modified 8-mode cycle. Thus, the highest PNA concentrations are found in the Inco Hot cycle exhaust. The next highest PNA concentrations are found in the Steady-state exhaust and the lowest PNA concentrations are found in the exhaust from the Modified 8-mode cycle. Again, the results indicate that the PNA levels are altered significantly by a change in the operating conditions.

Finally, the 8-Mode cycle can be compared with the other cycles. Two of these comparisons, the 8-Mode with the Modified 8-mode and with the Inco Hot cycle are of particular interest because they demonstrate how a lug-down influences the PNA concentrations in the exhaust. The PNA levels are much lower in the exhaust from an 8-Mode cycle than they are for the other modes of operation. In fact, the observed Total PNAs, Total-pyrene and Total Carcinogenic

PNAs in the 8-Mode cycle exhaust are only 46%, 60% and 58%, respectively, of those in the Modified 8-mode cycle, 44%, 64% and 73%, respectively of those found in the exhaust from the Inco Hot cycle and 67%, 80% and 42% respectively, of those in the exhaust from the Steady-state operation. Although the temperature was not recorded at the sampling site during the 8-Mode cycle, one would expect it to be lower than 74°F (the temperature recorded during the Modified 8-mode cycle) because the temperature of the exhaust was a maximum during the lug-down phase (phase 2, Figure 3) in the Modified 8-mode cycle. Since the lug-down phase is the only difference between the two cycles, it is probable that the collection temperature for the 8-Mode exhaust was <74°F. Thus, the collection efficiency for the PNAs would be much higher for the 8-Mode cycle than for the Inco Hot cycle and the Steady-state mode. If the collection efficiency for the 8-Mode samples was 250% of that for the Inco Hot cycle and the Steady-state condition, the Total PNAs, Total-pyrene and Total Carcinogenic PNAs in the 8-Mode cycle exhaust would only equal 18%, 26% and 29% respectively, of the PNAs in the exhaust from the Inco Hot cycle and 27%, 32% and 17% respectively, of the PNAs in the exhaust from the Steady-state operation. Thus, the exhaust from the 8-Mode cycle has by far, the lowest concentrations of PNAs. The PNA concentrations in the exhaust increase in the order 8-Mode cycle < Modified 8-mode cycle < Steady-state conditions < Inco Hot cycle and again one must conclude that the operating conditions affect the PNA concentrations in the exhaust markedly.

Unfortunately, no Ames analyses were performed on Hi Vol filters collected during the 8-Mode cycle and we are unable to indicate whether changing the cycle always alters the mutagenicity of the exhaust. However, in the only two samples where the mutagenicities can be compared, changing the cycle did affect the mutagenicity of the exhaust. This suggests that both the PNA concentrations and the mutagenicity of the exhaust is dependent on the operating mode of the diesel. This conclusion is consistent with that suggested earlier (7), i.e., that the PNA concentrations and the mutagenicity of the diesel exhaust was very different when different portions of the L.H.D. cycle were monitored.

Finally, one can determine how a lug-down affects the PNA concentrations downstream from a 912-W Deutz diesel. The only difference between the 8-Mode and the Modified 8-mode cycle (columns 1 and 4, Table 5) is phase 2, i.e., in phase 2 of the 8-Mode cycle the engine speed is high (1840 rpm) and the load is low (the torque is only 156 ft-lbs). In the Modified 8-mode cycle, phase 2 represents a lug-down operation where the engine speed is low (only 1610 rpm) and the load (torque) is a maximum of 222 ft-lbs. Since the 1840 rpm - 156 ft-lb phase is similar to the other phases of the 8-Mode cycle, the PNAs released in (phase 2 of the 8-Mode cycle should be similar to those released in the other 7 phases). Thus, any differences between the 8-Mode cycle exhaust and the exhaust from the Modified 8-mode cycle can be attributed to the PNAs released in the lug-down phase. A comparison of the PNA concentrations in the exhaust from the 8-Mode and Modified 8-mode cycles indicates that higher concentrations of PNAs are released in

the exhaust during a lug-down. This conclusion is more clearly shown by the $\%\left(\frac{\text{Modified 8-mode}}{\text{8-Mode}}\right)$ ratios in Table 6. All but one of these ratios, which express the PNA concentrations in the exhaust from the two 8-Mode cycles as a percentage, are greater than 100% indicating that all but one of the PNAs is more concentrated in the exhaust from the Modified 8-mode cycle. Moreover, the corresponding ratios for the Total PNAs, the Total-pyrene and the Total Carcinogenic PNAs are 217%, 168% and 171% respectively. If one assumes that the PNAs released/second in the exhaust from phase 2 of the 8-Mode cycle are close to those released in the other 7 phases of the 8-Mode cycle, any differences between the Modified 8-mode cycle and the 8-Mode cycle must arise because different quantities of PNAs are released during the lug-down. Since the PNAs in the exhaust from the Modified 8-mode cycle are approximately twice as concentrated as those from the 8-Mode cycle, the PNA concentrations are obviously much higher in the exhaust during the 40 second lug-down period. If the above assumption is valid, the increased amount of PNAs released/second during the lug-down can be estimated from the following equation

$$\left(\frac{\text{Total PNA concentration Modified 8-mode}}{\text{Total PNA concentration 8-Mode}}\right) = 2.17 = \left(\frac{\frac{40}{300}x + \frac{260}{300}y}{\frac{300}{300}y}\right)$$

where x is the amount of Total PNAs released/second during the 40 second lug-down in the 300 second Modified 8-mode cycle and y is the average amount of Total PNAs released/second during the other 240 seconds of the Modified 8-mode cycle and in the 8-Mode cycle. Solving for the x/y ratio shows that $x/y = 9.8$ or that

Table 6 - The affect of a Lug-Down on the PNA concentrations[a] in the dilute exhaust

	$\%\left\{\frac{\text{Modified 8-mode cycle}}{\text{8-Mode cycle}}\right\}$	$\%\left\{\frac{\text{Inco Hot cycle}}{\text{8-Mode cycle}}\right\}$	$\%\left\{\frac{\text{Inco Hot cycle}}{\text{Modified 8-mode cycle}}\right\}$
Pyrene	310	355	115
Fluoranthene	281	308	110
Benzo(a)anthracene*	190	142	75
Benzo(e)pyrene	123	122	99
Perylene	204	121	59
Benzo(k)fluoranthene	192	153	79
Benzo(a)pyrene*	90	89	99
Benzo(ghi)perylene*	156	103	66
Dibenzo(a,h)anthracene*	0	0	0
Dibenzo(def,mno)chrysene	414	473	114
Naptho(1234,def)chrysene*	227	225	99
Benzo(rst)pentaphene*	264	206	78
Total PNAs	217	225	106
Total-pyrene	168	157	94
Total Carcinogens	171	136	80
Average Temperature at the sampling site (°F)[c]	74/<74[b]	93/<74[b]	93/74

* Carcinogenic PNAs

[a] These results were calculated from the PNA concentrations in the exhaust from the 8-Mode cycle (column 4) the Modified 8-mode cycle (column 1) and the Inco Hot cycle (column 2) of Table 5.

[b] This temperature was not recorded. It was estimated from those observed in the other cycles as <74°F.

[c] The temperature ratios are the ratios of the average temperatures at the sampling sites for the two cycles.

approximately 10 times more PNAs are released/second during the lug-down in the Modified 8-mode cycle than in the rest of the cycle. If the same calculation is carried out using the Total Carcinogenic PNAs, the ratio only equals 1.71 (see column 2, Table 6) and the $^{x}/_{y}$ ratio is only 6.3. This means that the carcinogenic PNAs are only 6 times more concentrated in the lug-down exhaust. This suggests that the exhaust released during the lug-down should be less mutagenic than the exhaust released during the rest of the cycle[1].

A similar comparison between the Inco Hot cycle and the 8-Mode cycle (column 2, Table 6) can be used to estimate the effect of a lug-down. Again, all of the PNAs are more concentrated in the exhaust from the Inco Hot cycle than in the exhaust from the 8-Mode cycle and when one considers that the average temperature at the sampling site was 21°F higher during the Inco Hot cycle, i.e., the collection efficiency is 250% higher for the 8-Mode cycle than for the Inco Hot cycle, all of the PNAs would be more concentrated in the exhaust from the Inco Hot cycle. In addition, the ratios for the Total PNAs, the Total-pyrene and the Total Carcinogenic PNAs without correcting for temperature are all greater than 100%, i.e., they are 225%, 157% and 136% respectively. The temperature corrected ratios would be 563%, 393% and 340%, respectively.

1. This is only true if a significant proportion of the mutagenicity is a result of the PNAs in the exhaust. In fact, more than 50% of the mutagenic response in the exhaust extracts from the 912-W Deutz diesel is not caused by the mononitro PNAs (vide-infra). Thus, this requirement may be fulfilled and one might find that the mutagenicity of the lug-down exhaust is lower than that found in the other portion of the cycle.

Obviously, the PNAs are much more concentrated in the exhaust from the Inco Hot cycle. Since the lug-down in the Modified 8-mode cycle led to much higher PNAs, it is reasonable to assume that any large differences between the 8-Mode and the Inco Hot cycle would be due to the 45 second lug-down in the Inco Hot cycle. If one assumes that the PNAs released/second during the rest of the Inco Hot cycle are equal to those released/second in the exhaust in the 8-Mode cycle, one can again estimate the relative amounts of PNAs released in the exhaust during the lug-down and the rest of the Inco Hot cycle.

If the temperature corrected (Inco Hot cycle/8-Mode cycle) ratios are used, the equation for the Inco Hot cycle and the 8-Mode cycle becomes

$$\left\{\frac{\text{Total PNAs Inco Hot cycle}}{\text{Total PNAs 8-Mode cycle}}\right\} = \frac{2.25}{1} \times \frac{2.50}{1} = \left\{\frac{\frac{45}{300}x + \frac{255}{300}y}{\frac{300}{300}y}\right\}$$

where the $^{2.50}/_{1}$ corrects for the temperature difference at the sampling sites during the 300 second cycles. Solving the equation indicates that $^{x}/_{y} = 31.8$ or that 32 times more PNAs are released per second during the lug-down than during the rest of the Inco Hot cycle. If the corresponding $^{x}/_{y}$ ratio is determined for the Total Carcinogenic PNAs, only 17 times more PNAs are released/second during the lug-down. Thus, again, it appears that the exhaust from the lug-down should be less mutagenic than the the exhaust released during the rest of the cycle.

It is worth noting however, that the above calculations are based on the assumption that the same amounts of PNAs are

released/second from the 5 other phases of the Inco Hot cycle and the 8-Mode cycle. In fact, this may not be the case.

A comparison of the results from the Modified 8-mode and the Inco Hot cycle, column 3, Table 6, show that the PNA concentrations in the exhaust are equal for these two cycles. Although the observed PNA concentrations are equal in the two modes, the temperatures at the sampling sites were quite different. This means that the PNA concentrations in the exhaust from the Inco Hot cycle are approximately 2.5 times higher than those in the exhaust from the Modified 8-mode cycle. Unfortunately, we do not have any way of determining whether the PNAs are 2.5 times higher during the whole cycle or just during the lug-down periods. The equivalence of the PNAs in the two cycles however, suggests that the PNAs are probably 2.5 times more concentrated in the exhaust throughout the whole Inco Hot cycle. If this is the case, the corresponding $^{x}/_{y}$ ratios for the Total PNAs and the Total Carcinogenic PNAs are only 10 and 6, respectively. Thus, the excess amount of PNAs released/second during the lug-down cannot be estimated accurately. In spite of this, it seems safe to conclude i) that between 10 and 32 times more PNAs are released in the exhaust per second during the lug-down (mucking) phase than during the other (hauling and dumping) phases of an LHD cycle and ii) that between 6 and 17 times more carcinogenic PNAs are released in the exhaust per second during the lug-down of the Inco Hot cycle and the Modified 8-mode cycle. Thus, the exhaust from the lug-down phase of the 912-W Deutz diesel should be less

mutagenic than the exhaust from the rest of the Inco Hot cycle or the Modified 8-mode cycle.

Finally, it is worth noting that these results substantiate the conclusions based on our earlier work (7). Our earlier underground sampling had led us to conclude that the exhaust contained very different amounts of PNAs and nitro PNAs (the mutagenicity of the exhaust was different) when samples were collected at different points in an LHD cycle. The above results corroborate this finding because the amounts of PNAs and the mutagenicity of this exhaust are quite different during the lug-down (at a mucking site) in the LHD cycle than they are at other positions (tramming or dumping) in the LHD cycle. Obviously, one has to be very careful in comparing results because the PNA concentrations and the mutagenicities are highly dependent on factors such as the temperature at the sampling site and on the operating mode of the diesel.

The Effect of a Corning Diesel Exhaust Filter on Exhaust Emissions:-

Finally, the effect of adding a Corning Diesel Exhaust filter to the exhaust system of a 912-W Deutz diesel was determined. The effect of this new exhaust filter was established by comparing the PNA concentrations and the mutagenicities of the Hi Vol filters collected at the sampling site, Figures 1 and 2, when the diesel was operating in the Modified 8-mode and Inco Hot cycles with and without a Corning filter in the exhaust system. The results of the PNA analyses are given in Table 7 and the results

Table 7 - The effect of adding a Corning filter to the exhaust train of a 912-W Deutz diesel engine

	Concentrations in ng/m^3					
	Modified 8-mode cycle				Inco Hot cycle	
	No Filter Sample #34	With Filter Sample #28	With Filter Sample #30		No Filter Sample #40	With Filter Sample #46
			First Analysis	Total Both Analyses		
Pyrene	462	68.7	60.5	146	529	34.7
Fluoranthene	115	3.48	6.90	13.4	126	12.6
Benzo(a)anthracene*	56.4	6.37	32.9	86.8	42.3	7.42
Benzo(e)pyrene	179	27.5	26.0	55.1	177	23.1
Perylene	4.69	0.39	0.86	1.03	2.78	0.64
3-Methylcholanthrene*	0	0	1.75	3.06	0	0
Benzo(k)fluoranthene	30.4	4.01	7.64	8.18	24.1	4.36
Benzo(a)pyrene*	11.7	0.45	2.67	2.80	11.6	1.72
Benzo(ghi)perylene*	43.0	3.89	10.0	10.7	28.4	2.98
Dibenzo(a,h)anthracene*	0	0	3.87	10.2	0	0
Dibenzo(def,mno)chrysene	2.65	0.25	1.18	2.82	3.03	0.63
Naptho(1234,def)chrysene*	28.8	2.18	0	4.96	28.6	2.25
Benzo(rst)pentaphene*	6.07	1.52	0	0.35	4.73	1.63
Total PNAs	940	119	154	345	977	92.0
Total-pyrene	478	50.0	93.8	199	448	57.3
Total Carcinogens	146	14.4	51.2	119	116	16.0

* Carcinogenic PNAs

of the Ames testing are given in the Appendix[1]. A synopsis of the PNA concentrations and mutagenicities for these samples are given in Table 8.

An examination of the PNA concentrations in Table 7 indicates that the PNA concentrations are much lower in the exhaust when a Corning Diesel Exhaust Filter is added to the exhaust system of a 912-W Deutz Diesel. In fact, a comparison of the results from filters 34 and 28 collected while the diesel was working on a Modified 8-mode cycle indicates that the concentrations of all of the PNAs are lower when the Corning filter is used. In fact, the PNA concentrations in the filtered exhaust range from a high of 25% to a low of 3% of the corresponding concentrations in the untreated exhaust. The Total PNAs, Total-pyrene and Total Carcinogenic PNAs are also much lower in the treated exhaust. For example, the Total PNAs, the Total-pyrene and the Total Carcinogenic PNAs in the treated exhaust are only 13%, 11% and 10%, respectively, of the corresponding Totals for the unfiltered exhaust.

A second Hi Vol filter, #30, which was collected when the Corning Exhaust filter was in the exhaust system and the diesel was operating the Modified 8-mode cycle, was also analyzed for PNAs in an effort to confirm the above results. Unfortunately, problems developed during the analysis of this filter. As a result, we do not know how to treat the results we have obtained. The problem was that the group E PNAs did not separate on the

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1. The Ames analyses were performed by Mr. A.J. Horton, Ontario Research Foundation, Mississauga, Ontario.

Table 8 - The effect of adding a Corning filter on the PNA concentrations and mutagenicity of the exhaust from a 912-W Deutz diesel working on a Modified 8-mode and an Inco Hot cycle

	Modified 8-mode No Corning Filter	Average Modified 8-mode No Filter	Modified 8-mode with Corning Filter	Average Modified 8-mode with Filter	Inco Hot Cycle No Corning Filter	Average Inco Hot Cycle No Filter	Inco Hot Cycle with Corning Filter	Average Inco Hot Cycle with Filter
Total PNAs ng/m^3	940	940	119[a]	119	977	977	92.0	92.0
Total-pyrene ng/m^3	478	478	50.0[a]	50.0	448	448	57.3	57.3
Total Carcinogens ng/m^3	146	146	14.4[a]	14.4	116	116	16.0	16.0
Specific Mutagenicity TA98-S9	0.49, 0.72	0.61	0.75, 0.21[c]	0.48	0.34, 0.88	0.61	0[b], 0.37	0.37
Specific Mutagenicity TA98-NR	0.23, 0.42	0.33	0.29, NM	0.29	0.39, 0.42	0.41	0[b], 0.23	0.23
Average Revertants/m^3 TA98-S9	648, 1165	907	64.0, 8.70	36.4	273, 413	344	0[b], 39.0	39.0
Average Revertants/m^3 TA98+S9	1150 NM	1150	NM, NM	NM	NM, 408	408	NM, 55.0	55.0
Average Revertants/m^3 TA98-NR	304, 680	492	24.7, NM	24.7	314, 197	256	0[b], 24.0	24.0

[a] Hi Vol filter #28 only. The results from filter #30, Table 7 were not reliable.

[b] The amount of exhaust extract used in the Ames analyses was too small to give a positive mutagenic response.

[c] This value is not thought to be reliable. NM- not measured.

acetylated cellulose TLC plate. As a result, this plate was eluted and rerun on both the aluminum oxide and acetylated cellulose TLC plates. PNAs from each group were found in the second analysis and these were added to those found in the initial analysis. We do not know which set of results is correct because we do not understand what happened in the analysis of Hi Vol filter #30. As a result, we have included the results from the first analysis and the Total of the two analyses in Table 7. All of the PNAs from the first analysis of Hi Vol filter #30 are less concentrated in the treated exhaust. In fact, the individual PNAs in the treated exhaust range from 6 to 58% of those in the untreated exhaust and the Total PNAs, Total-pyrene, and Total Carcinogenic PNAs are only 16%, 19% and 31% of those found in the untreated exhaust. When the totals for the first and second analyses of filter #30 are compared with those for the untreated exhaust, two of the PNAs are more concentrated (154% and 106%) in the treated exhaust. The remaining nine PNAs range from 6 to 32 percent of the PNA concentrations in the untreated exhaust. In addition, the Total PNAs, the Total-pyrene and the Total Carcinogenic PNAs for the sum of the first and second analyses of the treated exhaust are only 35%, 39% and 73%, respectively, of the corresponding totals for the untreated exhaust. Although the results from Hi Vol filter #30 are not in good agreement with those from filter #28, the results indicate that the Corning Exhaust filter does reduce the PNA concentrations in the exhaust

significantly. More samples would have to be run to determine the exact magnitude of the reduction in the PNAs by the Corning filter when the diesel was operating in the Modified 8-mode cycle.

A comparison of the PNA concentrations for the treated and untreated exhaust from the Inco Hot cycle also shows that the Corning Diesel Exhaust filter reduces the PNAs in the exhaust significantly. All of the individual PNA concentrations are lower in the treated exhaust. For example, the PNAs in the treated exhaust range from a high of 35% to a low of 7% of those in the untreated exhaust. In addition, the Total PNAs, Total-pyrene and Total Carcinogenic PNAs in the treated exhaust only account for 13%, 11% and 10%, respectively, of the corresponding Totals in the untreated exhaust from the Inco Hot cycle.

Obviously, the Corning Diesel Exhaust filter reduces the PNA concentrations in the exhaust significantly whether the diesel is operating on the Modified 8-mode cycle or the Inco Hot cycle. A more important finding, however, is that both the carcinogenic and non-carcinogenic PNAs in the exhaust appear to be reduced by the same amount. Thus, although much more work has to be done to determine the exact percentage of the PNAs that are removed from the exhaust by the Corning filter, there is no doubt that this filter removes significant amounts of PNAs in the exhaust. In fact, this filter is superior to any other filter we have tested in this regard (7).

An analysis of the mutagenicities in Table 8 shows that

the Corning Diesel Exhaust filter also reduces the mutagenicity of the diesel exhaust whether the diesel is operating on the Modified 8-mode cycle or the Inco Hot cycle. The specific mutagenicities of the exhaust extracts from Hi Vol filters collected at the sampling sites, Figures 1 and 2, are very similar. In fact, if one only calculated the specific mutagenicities one would conclude that the Corning filter did not reduce the mutagens in the exhaust significantly. For example, the average specific mutagenicity of the exhaust extracts for the Modified 8-mode cycles are only slightly lower when the Corning filter is installed in the exhaust system of the diesel, i.e., the specific mutagenicities of the exhaust when Salmonella strain TA98-S9 is used in the Ames analyses are 0.61 and 0.48 although the 0.21 value found when the Corning filter is used is suspect (see Appendix). In fact, if the 0.21 value is discarded, the specific mutagenicity of the treated exhaust is greater than that of the untreated exhaust. Similar results were obtained when the Ames analysis was done using the TA98-NR strain of bacteria. Here the specific mutagenicities of the treated and untreated exhaust (0.29 and 0.33, respectively) are within experimental error of one another.

The same relationship is observed with the samples collected during the Inco Hot cycle. Although the average specific mutagenicity of the untreated exhaust (0.61) is higher than that of the treated exhaust (0.37), the 0.37 value is higher than the 0.34 revertants/μg found for one of the untreated

exhaust samples. Again, it is difficult to conclude that the treated exhaust has a lower specific mutagenicity than the untreated exhaust. The only comparison where one can safely conclude that the specific mutagenicity is lower in the treated exhaust is when the Hi Vol filters collected during the Inco Hot cycle were analyzed using the Salmonella TA98-NR strain of bacteria. In this case the specific mutagenicity of the treated exhaust is approximately $^2/_3$ of the specific mutagenicity of the untreated exhaust.

Thus, although the trend is to lower specific mutagenicities for the treated exhaust, the differences between the treated and untreated exhaust are small and uncertain. This indicates that the mutagenic and non-mutagenic material in the exhaust is reduced by almost equal amounts when the Corning filter is inserted in the exhaust system of the 912-W Deutz diesel. It is worth noting that this conclusion is in complete agreement with that reached from the effect of the Corning filter on the carcinogenic and non-carcinogenic PNAs, i.e., that the Corning filter removes equal percentages of the carcinogenic and non-carcinogenic PNAs from the exhaust. If this is the case, one would expect that the amount of PNAs in the exhaust will be reduced when the Corning filter is used but that the specific mutagenicity (the average revertants/µg) of the exhaust extract would not be altered significantly.

Although the specific mutagenicities do not indicate whether the Corning Diesel Exhaust filter is effective in reducing the mutagens in the exhaust, the average revertants/m^3 in the

diluted exhaust clearly demonstrate that the Corning filter removes substantial amounts of the mutagenic material in the exhaust. When one examines the average revertants/m^3 found when the Ames analyses of the samples collected during a Modified 8-mode cycle were tested with the Salmonella strains TA98-S9, TA98+S9 and TA98-NR, it is obvious that the Corning filter greatly reduces the mutagenicity of the exhaust. The average revertants/m^3 for the treated exhaust only accounts for 4.0% and 5.0% of the average revertants/m^3 for the untreated exhaust, i.e., the average revertants/m^3 are reduced by 96 and 95% when the analysis is done with Salmonella strains TA98-S9 and TA98-NR, respectively.

A similar reduction in mutagenicity is observed with the treated and untreated exhaust collected during the Inco Hot cycle. Here, the average revertants/m^3 are reduced by 89%, 87% and 91%, i.e., the mutagenicity of the treated exhaust only accounts for 11%, 13% and 9% of the mutagenicity of the untreated exhaust when the Ames analyses are done using TA98-S9, TA98+S9 and TA98-NR, respectively.

Thus, although more testing is required to be confident of the magnitude of the reduction in the mutagenicity of the exhaust downstream from a diesel, one is forced to conclude that the Corning Diesel Exhaust filter reduces the mutagens (carcinogens) in the exhaust from a 912-W Deutz diesel markedly, i.e., it appears that between 87 and 96% of the mutagenic material is removed by the Corning filter.

One can also compare the behaviour of the Corning Diesel Exhaust filter during the Modified 8-mode and the Inco Hot cycles. An examination of the results in Table 8 indicates that the PNAs and the mutagenicities of the exhaust are virtually identical for the Modified 8-mode and the Inco Hot cycles. However, the temperature at the sampling site in the Inco Hot cycle was 21°F above that at the sampling site during the Modified 8-mode cycle. Since the collection efficiency of PNAs would be approximately 250% greater during the Modified 8-mode cycle than during the hotter Inco Hot cycle, it would appear that more PNAs and presumably more mutagenic material is released during the Inco Hot cycle.

It is worth speculating on the reason why the PNA concentrations and the mutagenicity (revertants/m^3) are higher for the Inco Hot cycle. Some of the difference may arise because different amounts of fuel are burned per second in the two cycles. For example, the $\%CO_2$ in the raw exhaust is greater for the Inco Hot cycle (8.8%) than for the Modified 8-mode cycle (6.1%). This finding is confirmed by the $\%CO_2$ at the sampling site, i.e., higher concentrations of CO_2 (0.13% versus 0.11%) were found at the sampling site during the Inco Hot cycle. Since carbon dioxide is produced when the fuel is burned, the amount of CO_2 in the exhaust should be related to the amount of fuel burned during the 300 second cycle. As a result, it would appear that more fuel was burned per unit time during the Inco Hot cycle. It is not too surprising therefore, that the PNA concentrations and the

revertants/m^3 of the exhaust collected for the whole cycle is higher for the Inco Hot cycle.

Another difference between the Modified 8-mode cycle and the Inco Hot cycle is the CO content in the exhaust gases entering the Corning filter. The CO concentration is higher (260 ppm versus 170 ppm) in the exhaust entering the Corning filter during the Inco Hot cycle suggesting that there is less complete combustion in the Inco Hot cycle. One would expect therefore, that the concentrations of unburned PNAs which are harder to ignite and burn, would be higher in the exhaust gases from the Inco Hot cycle. This is in fact, what is observed.

Other differences between the exhaust from the two cycles are the NO_x concentration and the operating temperature of the Corning filter. Higher concentrations of NO_x were found in the exhaust from the Inco Hot cycle. The NO_x was 612 ppm in the raw exhaust from the Inco Hot cycle and only 449 ppm in the raw exhaust from the Modified 8-mode cycle. Thus, one would expect higher concentrations of nitro PNAs and therefore a higher mutagenicity for the exhaust from the Inco Hot cycle. In fact, when the mutagenicities (revertants/m^3, Table 8) found for the dilute exhaust when TA98-S9, TA98+S9 and TA98-NR are used in the Ames analysis are temperature corrected, the average $\left\{\frac{\text{mutagenicity Inco Hot cycle}}{\text{mutagenicity Modified 8-mode cycle}}\right\} = 1.66 \pm 0.84$. It is interesting that the corresponding NO_x ratio of 1.36 is almost identical to the ratio of the mutagenicities.

Finally, the operating temperature of the Corning filter

was significantly higher in the Inco Hot cycle. In fact, the average temperature of the Corning filter was 865°F and the maximum filter temperature was 1080°F in the Inco Hot cycle. This temperature was hot enough to regenerate (burn some of the particulate trapped in the filter) during the cycle, (see Figure 4). The regeneration of the Corning filter was confirmed when it was found that the CO concentration in the gases leaving the Corning filter (300 ppm) was higher than the CO concentration in the exhaust gases entering the filter (260 ppm). This could only occur if some of the hydrocarbon was being oxidized to CO (burned off the filter) during the cycle.

The CO concentration in the exhaust gases entering and leaving the Corning filter during the Modified 8-mode cycle were the same. This indicated that no regeneration of the Corning filter was occurring during the cycle. This undoubtedly occurred because the average temperature during this cycle was only 647±9°F and the maximum filter temperature was only 954°F. Thus, the average operating and the maximum temperature of the Corning filter in the Modified 8-mode cycle were approximately 220°F and 130°F respectively, below the corresponding temperatures during the Inco Hot cycle.

Finally, it is worth noting that the mutagenic responses observed in the Ames analysis of the 912-W Deutz diesel exhaust extracts are different from those found for the exhaust from L714 Deutz diesels we tested in previous studies. The results in Table 8 show that the 912-W exhaust is mainly, if not completely,

composed of direct-acting mutagens, i.e., compounds that are mutagenic in their own right and do not need metabolic activation by the enzyme S9. This conclusion is warranted because the mutagenic response with TA98+S9 is equal or only slightly greater than that found when the Salmonella strain TA98-S9 was used in the Ames analysis. The mutagenic responses found for the exhaust extracts of the L714 diesels using TA98+S9 on the other hand, were almost always lower than those observed when the Ames analysis was carried out in the absence of S9 (7). Thus, there may be more indirect-acting mutagens in the exhaust from the 912-W Deutz diesel. However, the difference is small and the limited number of samples we analyzed make it difficult to tell if the 912-W exhaust does contain more indirect-acting mutagens.

A more important difference between the exhaust from the 912-W and the L714 Deutz diesels is the amount of mononitro PNAs in the exhaust. For the L714 diesels, the TA98-NR mutagenic response was only about 15% of the mutagenic response found when TA98-S9 was used in the Ames analysis. This indicated that almost all (85%) of the mutagens in the exhaust extract from the L714 diesels were mononitro PNAs. In contrast, the mutagenic response found for the exhaust extracts from the 912-W Deutz diesel when TA98-NR was used accounts for 65±9% of the mutagenic response found when the Salmonella strain TA98-S9 was used in the Ames analysis. Thus, only 35% of the mutagens in the 912-W exhaust are mononitro PNAs. We are unable to explain why the mutagens from these two diesels are so different. For example, we do not know

whether these differences in the mutagens are due to design differences in the two engines or whether they arise because the fuels were different or because the mutagens from the complete cycle, not just one portion of the LHD cycle, were collected in these experiments.

CONCLUSIONS

This work has finally established that temperature plays an important role in the sampling or collection efficiency of the PNAs in diesel exhaust. For example, reducing the temperature at the sampling site by 21°F (12°C) increases the sampling efficiency by approximately 250%, i.e., by a factor of 2.5 times. Although we do not have the data to confirm this, we believe that the collection efficiency of the nitro PNAs and other mutagens are affected by temperature in a similar manner. Obviously, the sampling (collection) of PNAs and nitro PNAs will have to be done at lower temperatures if one hopes to collect the PNAs and mutagens in diesel exhaust quantitatively and different sampling techniques will have to be developed before anyone can quote accurate PNA concentrations or mutagenicities for diesel exhaust. This test alone, indicates that as little as 30% of the PNAs and probably mutagens, are being trapped (collected) at temperatures of 95°F. Moreover, other studies suggest that the collection efficiency may not be quantitative even at lower temperatures (7). Thus, it is imperative that new, quantitative sampling techniques for diesel exhaust samples be developed so that one can be confident that the conclusions drawn from the results of important experiments such as those carried out in this study are correct.

This study has also demonstrated that the PNA concentrations and probably the mutagens in the dilute diesel exhaust are strongly dependent on the LHD cycle. For example, the Total PNAs in the cleanest cycle only account for 18% of the Total PNAs in

the exhaust from the cycle with the highest PNA concentrations. In fact, the PNAs concentrations in the exhaust increase in the order 8-Mode cycle < Modified 8-mode cycle < Steady-state < Inco Hot cycle. The mutagenic response is also different in the only two cycles we could compare. Thus, it appears that both the PNA concentrations and the mutgenic response are dependent on the LHD cycle. This obviously means that the PNA concentrations and mutagenicity of the exhaust depends on the portion of the LHD cycle that is being monitored in an experiment.

This study also demonstrated that more PNAs and more mutagens are released in the lug-down period of an LHD cycle. If some of our assumptions are correct, the Total PNAs are approximately ten times more concentrated in the exhaust from the lug-down phase. The carcinogenic PNAs on the other hand, are only about six times more concentrated in the exhaust from the lug-down. Thus, the lug-down exhaust is expected to be higher in PNAs but lower in carcinogenic PNAs, i.e., to have a lower mutagenicity. This may occur because the Fuel/Air ratio increases during the lug-down and there would be less complete combustion. As a result, the PNAs which are harder to burn, would increase in the exhaust. The mutagenicity is probably lower because i) the concentrations of the carcinogenic PNAs are not increased as much as the non-carcinogenic PNAs in the exhaust released during a lug-down and ii) because the NO_2 concentration is lower in the exhaust from a lug-down (19). This would reduce the mutagenicity by reducing the formation of the mutagenic nitro PNAs.

Finally, this study has demonstrated that the Corning Diesel Exhaust Filter reduces the PNAs, the Carcinogenic PNAs and the mutagens in the exhaust significantly. In fact, the Corning filter reduces the PNAs and Carcinogenic PNAs from the Modified 8-mode cycle by at least $^1/_3$ and probably by a factor of 10. The PNAs also appear to be reduced by a factor of 10 when the Corning filter is added to the exhaust system of a 912-W Deutz diesel working on an Inco Hot cycle.

The mutagenicities in revertants/m^3 were also much lower in the exhaust that had passed through the Corning filter. For example, the revertants/m^3 for the treated exhaust from the Modified 8-mode and Inco Hot cycles were only 4.5% and 11%, respectively, of those found for the untreated exhaust from these cycles whether the Ames analyses were done using the Salmonella strains TA98-S9, TA98+S9 or TA98-NR. Thus, the Corning filter appears to remove between 89 and 96% of the mutagens in the exhaust. The same reduction is not seen when the specific mutagenicities of the exhaust extract are compared. This presumably occurs because the Corning filter removes almost equal amounts of the mutagenic and non-mutagenic materials from the exhaust.

The results indicate that the exhaust from the Inco Hot cycle is higher in PNAs, mutagens, CO_2, CO and NO_x and is hotter than the exhaust from the Modified 8-mode cycle. This may be a result of the longer lug-down in the Inco Hot cycle. In any case, it appears that the Corning filter is regenerated at the higher temperatures that exist during the Inco Hot cycle. This is a

definite advantage from an operators point-of-view because the filter will not have to be removed and cleaned as often.

Finally, the results from the PNA and Ames analyses have shown that the mutagens in the exhaust from the 912-W Deutz diesel are quite different from those found in the exhaust from the L714 Deutz diesels. For example, the exhaust from the 912-W is higher in PNAs than any other diesel we have tested. Although the specific mutagenicity and the revertants/m^3 of the exhaust from the 912-W diesel is towards the low end of the corresponding results from the L714 diesels we have tested, the exhaust from the 912-W diesel seems to have slightly more indirect-acting mutagens than the exhaust from the L714 diesels. An even greater difference between the exhausts from the two diesels was the amount of mononitro PNAs in the exhaust. Approximately 85 percent of the mutagenic activity in the L714 Deutz diesel exhaust was due to mononitro PNAs and almost all of the rest of the activity could be attributed to polynitro PNAs (7,17). Only 35% of the mutagenic response for the 912-W exhaust could be attributed to mononitro PNAs. Unfortunately, the reason for these differences is not known.

EXPERIMENTAL

No new procedures were developed during the course of this work. The procedures used to collect the samples for PNA and the Ames bioassay are described on pages 4-6. The methods used in doing the quantitative analysis of the PNAs and the mutagens collected on the Hi Vol filters are described in detail elsewhere (5).

ACKNOWLEDGEMENTS

The authors are greatly indebted to Mr. Paul Mogan and Mr. Don Dainty, who provided the test facility and ran the diesel for all of the sampling. These scientists also collected some of the samples that were required to complete this study. The assistance of Mr. Eric Dainty is also gratefully acknowledged. We would also like to thank Mr. Rob Micklethwaite who did the PNA analysis on two of the Hi Vol filters collected from the 8-Mode cycle. Finally, the authors would like to thank Mr. Bill Elliott and Inco Metals Co. for lending us some sampling equipment.

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APPENDIX I

TABLE I: Ames Mutagenicity Plate Incorporation Assay Results for Dichloromethane Extracts from Hi Vol. Filter No. 35 (8-mode cycle-lug down, vent fan high, no filter)

Concentrations Hi Volume Filter Extract µg/plate	S-9* mix +/-	Salmonella Tester Strains						
		TA-98				TA-98NR		
		Histidine Revertants			(Average)	Histidine Revertants		(Average)
600	-	242	212	182	(212)			
500	-	169	211	186	(189)			
400	-	211	173	172	(185)	81		
300+	-	174	171	199	(181)			
200+	-	134	144	125	(134)	71	70	
100+	-	81	73	85	(80)			
80+	-	46	40	51	(46)			
0	-				(22)			(12)
S.A.			0.49					
Mutar			6.0					

* - Metabolic Activation Mixture

\+ - linear portion of dose-response curve

S.A. - Specific Activity (average revertants/µg for linear portion of dose-response curve)

Mutar - Mutagenic Activity Ratio

Soluble organic fraction from Hi Volume Filter No. 35 11.8 mg

Volume of air sampled $8.9 m^3$.

TABLE 1A: Ames Mutagenicity Plate Incorporation Assay Results for Dichloromethane Extracts from Hi Vol. Filters Nos. 33, 36, 37, 38 (8-mode cycle - lug down, vent fan high, no filter)

Concentration Hi Volume Filter Extract µg/plate	Salmonella Tester Strains											
	Without Metabolic Activation								With Metabolic Activation			
	TA-98						TA-98NR				TA-98	
	Histidine Revertants					(Average)	Histidine Revertants			(Average)	Histidine Revertants			(Average)
800	212	261	291			(255)								
500	293	202	290			(262)	144	115	113	(124)	253	261	229	(248)
400†	277	254	293			(275)	134	119	113	(122)	262	269	244	(258)
300†	265	239	233			(246)	129	128	117	(125)	274	232	180	(229)
200†	184	175	189			(183)	110	77	110	(99)	204	186	210	(200)
100†	148	119	157			(141)	69	62	74	(68)	129	122	121	(124)
0	47	53	39	53	34	(45)	25	24	13	14	14	(18)	41	39	32	44	41	(39)
S.A.	0.72						0.42				0.71			
Mutar	8.2										5.6			

Metabolic Activation Mixture - S-9 Mix

† - Linear portion of dose-response curve

S.A. - Specific Activity (average revertants/µg for linear portion of dose-response curve)

Mutar - Mutagenic Activity Ratio

Soluble organic fraction from Hi Volume Filters Nos. 33, 36 17.2 mg

37, 38 11.8 mg

Total Volume of air sampled 17.9m^3

TABLE 2: Ames Mutagenicity Plate Incorporation Assay Results for Dichloromethane Extracts from Hi Vol. Filter No. 29 (8-mode cycle - lug down, vent fan high, filter)

Concentration Hi Volume Filter Extract µg/plate	S-9* mix +/-	Salmonella Tester Strains											
		TA-98							TA-98NR				
		Histidine Revertants					(Average)		Histidine Revertants				(Average)
600	-	232	73	160			(155)		165				(165)
500	-	228	198	158			(195)						
400	-	221	194	199			(205)		134	115			(125)
300†	-	223	193	223			(213)						
200†	-	162	196	145			(168)		76	78			(77)
100†	-	144	110	117			(124)						
80†	-	84	55	70			(70)						
0	-	20	26	16	28	20	(22)		11	11	13		(12)
S.A.		0.75											
Mutar		6.8											

* - Metabolic Activation Mixture

† - Linear portion of dose-response curve

S.A. - Specific Activity (average revertants/µg for linear portion of dose-response curve)

Mutar - Mutagenic Activity Ratio

Soluble organic fraction from Hi Volume Filter No. 29 9.2 mg
Volume of air sampled 107.9m^3.

TABLE 2A: Ames Mutagenicity Plate Incorporation Assay Results for Dichloromethane Extracts from Hi Vol. Filters Nos. 27 & 31 (8-mode cycle - lug down, vent fan high, filter)

Concentration Hi Volume Filter Extract µg/plate	Salmonella Tester Strain			
	Without Metabolic Activation			
	TA-98			
	Histidine Revertants			(Average)
1000	103	78	91	(91)
800	87	130	97	(105)
500	94	96	104	(98)
400†	120	100	99	(106)
300†	100	106	96	(101)
200†	104	79	93	(92)
100†	76	79	62	(72)
0				(45)
S.A.	0.21			
Mutar	2.2			

† - Linear portion of dose-response curve

S.A. - Specific Activity (average revertants/µg for the linear portion of dose-response curve)

Mutar - Mutagenic Activity Ratio

Soluble organic fraction from Hi Volume Filters Nos. 27, 31 10.8 mg

Total Volume of air sampled 261.8m^3.

TABLE 3: Ames Mutagenicity Plate Incorporation Assay Results for Dichloromethane Extracts from Hi Vol. Filter No. 41 (INCO "Hot" Cycle, vent fan high, no filter)

Concentration Hi Volume Filter Extract µg/plate	S-9* mix +/-	Salmonella Tester Strains					
		TA-98				RA-98NR	
		Histidine Revertants			(Average)	Histidine Revertants	(Average)
600	-	160	138	145	(148)		
500†	-	165	161	164	(163)		
400†	-	137	125	163	(142)		
300†	-	88	135	113	(112)		
200†	-	89	89	118	(99)	89	
100†	-	50	76	75	(67)		
0	-				(22)		(12)
S.A.			0.34				
Mutar			5.0				

* - Metabolic Activation Mixture

† - Linear portion of dose-response curve

S.A. - Specific Activity (average revertants/µg for linear portion of dose-response curve)

Mutar - Mutagenic Activity Ratio

Soluble organic fraction from Hi Volume Filter No. 41 7.3 mg

Volume of air sampled 9.1m^3

TABLE 3A: Ames Mutagenicity Plate Incorporation Assay Results for Dichloromethane Extracts from Hi Vol. Filters Nos. 39, 42, 43, 44 (INCO "Hot" cycle, vent fan high, no filter)

Concentration Hi Volume Filter Extract µg/plate	Salmonella Tester Strains											
	Without Metabolic Activation*								With Metabolic Activation			
	TA-98				TA-98NR				TA-98			
	Histidine Revertants			(Average)	Histidine Revertants			(Average)	Histidine Revertants			(Average)
1000	277	355	324	(319)								
800	252	327	412	(330)								
500†	298	357	338	(331)								
400†	290	320	337	(316)	112	117	111	(113)	371	355	402	(376)
300†	213	248	309	(257)	111	101	139	(117)	266	318	313	(299)
200†	368	256	209	(278)	102	99	116	(106)	202	205	199	(202)
100†	177	205	140	(174)	77	82	91	(83)	117	138	147	(134)
0				(45)				(18)				(39)
S.A.	0.88								0.87			
Mutar	10.2								8.6			

*Metabolic Activation Mixture - S-9 mix

† - Linear portion of dose-response curve

S.A. - Specific Activity (average revertants/µg for linear portion of dose-response curve)

Mutar - Mutagenic Activity Ratio

Soluble organic fraction from Hi Volume Filter Nos. 39, 42 9.0 mg

43, 44 8.1 mg

Total Volume of air sampled 36.4m^3

TABLE 4: Ames Mutagenicity Plate Incorporation Assay Results for Dichloromethane Extracts from Hi Vol. Filter No. 47 (INCO "Hot" Cycle, vent fan high, filter)

Concentration Hi Volume Filter Extract µg/filter	S-9* mix +/-	Salmonella Tester Strain							
		TA-98				TA-98NR			
		Histidine Revertants			(Average)	Histidine Revertants			(Average)
600	-	26	28	52	(35)				
500	-	26	78	27	(44)				
400	-	49	52	58	(53)	35	28		(32)
300	-	23	22	35	(27)				
200	-	25	35	33	(31)	28	26		(27)
100	-	28	45	26	(33)				
0	-				(22)				(12)
Mutar			1.1						

* - Metabolic Activation Mixture

Mutar - Mutagenic Activity Ratio

Soluble organic fraction from Hi Volume Filter No. 47 13.0 mg

Volume of air sampled 80.9m^3.

TABLE 4A: Ames Mutagenicity Plate Incorporation Assay Results for Dichloromethane Extracts from Hi Vol. Filters Nos. 45 & 48 (INCO "Hot" cycle, vent fan high, filter)

Concentration Hi Volume Filter Extract µg/plate	Salmonella Tester Strains											
	Without Metabolic Activation*								With Metabolic Activation			
	TA-98				TA-98NR				TA-98			
	Histidine Revertants			(Average)	Histidine Revertants			(Average)	Histidine Revertants			(Average)
1000	117	136	146	(133)								
800	138	137	135	(137)								
500	116	122	173	(137)								
400†	172	125	141	(146)	63	80	65	(69)	224	206	192	(207)
300†	151	125	137	(138)	67	84	57	(69)	199	160	192	(184)
200†	121	118	144	(127)	85	63	66	(71)	176	123	143	(147)
100†	96	99	97	(97)	52	53	52	(52)	97	95	117	(103)
0				(45)				(18)				(39)
S.A.	0.37				-				0.52			
Mutar	3.6				-				4.3			

*Metabolic Activation Mixture - S-9 mix

† - Linear portion of dose-response curve

S.A. - Specific Activity (average revertants/µg for linear portion of dose-response curve)

Mutar - Mutagenic Activity Ratio

Soluble organic fraction from Hi Volume Filters Nos. 45, 48 16.7 mg

Total Volume of air sampled 158.7m^3.

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November 16, 1982

Dr. K. Westaway,
Department of Chemistry,
Laurentian University,
Sudbury, Ontario.
P3E 2C6

Dear Ken,

Enclosed are the results (raw data) of Ames Mutagenicity testing conducted for two cycle conditions with and without filter type exhaust purifiers. Tables 1 and 1A present the results for the raw engine and 8-mode cycle lug-down. The specific activity value of 0.61 initially reported for Hi Volume Filter No. 35, by telephone, has been revised to 0.49 revertants per microgram for Salmonella tester strain TA-98 without metabolic activation. Table 1A presents the results of a retesting of the raw engine/8-mode cycle lug-down using High Volume Filter Samples Nos. 33, 36, 37 and 38. A specific activity of 0.72 revertants per microgram was obtained for Salmonella tester strain TA-98 without metabolic activation.

Tables 2 and 2A present the results of testing the diesel engine equipped with filter type exhaust purifiers for the 8-mode cycle lug-down. The specific activity value of 0.79 initially reported for High Volume Filter No. 29, by telephone, has been revised to 0.75 revertants per microgram for Salmonella tester strain TA-98 without metabolic activation. Table 2A presents the results of retesting of the engine equipped with filter type exhaust purifiers for the 8-mode lug-down. Testing of High Volume Filter Nos. 27 and 31 are suspect, due to problems encountered during extraction. It is my opinion that these data are unreliable and should be omitted when evaluating the performance of the filter type exhaust purifiers.

Tables 3 and 3A present the results obtained for the base engine and INCO "Hot" cycle. The specific activity value of 0.28 initially reported for High Volume Filter No. 41, by telephone, has been revised to 0.34 revertants per microgram for Salmonella tester strain TA-98 without metabolic activation. Table 3A presents the results of a retesting of the base engine/INCO "Hot" cycle using High Volume Filter Samples Nos. 39, 42, 43, and 44. A specific activity of 0.88 revertants per microgram was obtained for Salmonella tester strain TA-98 without metabolic activation.

Tables 4 and 4A present the results of testing the diesel engine equipped with filter type exhaust purifiers for the INCO "Hot" cycle.

Table 4 presents the results of testing High Volume Filter No. 47. This sample shows a negative mutagenic response for Salmonella tester strain TA-98 without metabolic activation. Table 4A presents the results of a retesting of the diesel engine equipped with filter type exhaust purifiers for the INCO "Hot" cycle using High Volume Filter Samples Nos. 45 and 48. A specific activity of 0.37 revertants per microgram was obtained for Salmonella tester strain TA-98 without metabolic activation.

The retesting of samples using the remaining high volume filter samples collected at the same time did not produce good agreement of data. The results presented in Table 2A should be disregarded due to problems encountered during sample extraction. The specific activity values obtained for samples of raw exhaust and exhaust from the filter type purifiers for both cycle conditions are expected to be in better agreement when corrected for the volume of exhaust sampled. It is also expected because of the longer sampling times required to collect sufficient sample with the exhaust filter in place, that the filter type devices reduce the direct-acting mutagens in the diesel exhaust.

It should be noted that there is a difference between the two cycle conditions in terms of the type of chemical mutagens responsible for the observed mutagenic activity. The INCO "Hot" cycle results indicate the presence of less nitro-substituted materials and a higher concentration of material requiring metabolic activation.

I hope these results will allow you to complete your report. For detailed information regarding methodology etc., please refer to our Report No. ACS7-81236 dated April 24, 1981. If you have any questions regarding this data please do not hesitate to call.

Yours sincerely,

A.J. Horton
Senior Technologist
Department of Applied Chemistry

AJH:EL
Enc.